Highlights from the spin PWG

Kensuke Okada (RBRC)
for the spin PWG
PHENIX collaboration meeting
July 18, 2008

Topics covered by the SpinPWG

What is the spin structure of proton?

—Longitudinal spin structure

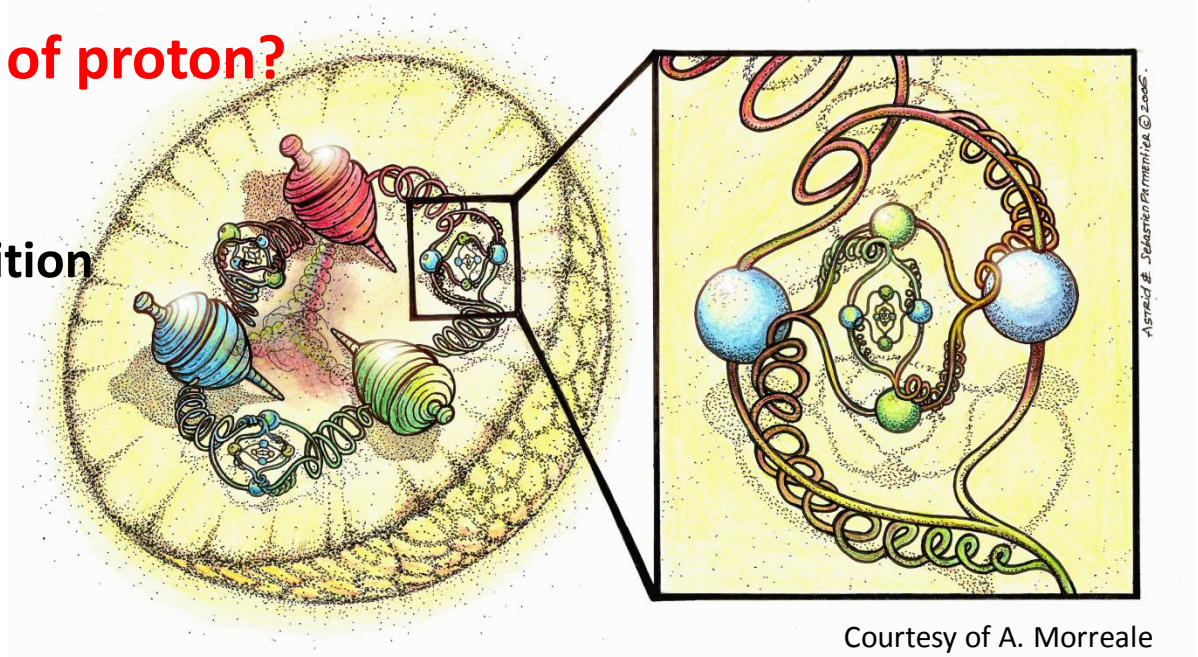
Gluon polarization

(Anti-)quark flavor decomposition

—Transverse spin structure

Transversity

Orbital angular momentum



Courtesy of A. Morreale

Method

The basic idea :

To see the spin effect, measure the difference between spin orientations.

A_LL, A_L, A_TT, A_N, …

D_LL, D_LS, …

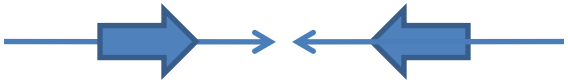
PHENIX datasets

Longitudinally Polarized Runs

The program for gluon polarization (Δg)

Year	√s [GeV]	Recorded L	Pol [%]	FOM (P^4L)
2003 (Run 3)	200	.35 pb^{-1}	27	1.9 nb^{-1}
2004 (Run 4)	200	.12 pb^{-1}	40	3.1 nb^{-1}
2005 (Run 5)	200	3.4 pb^{-1}	49	200 nb^{-1}
2006 (Run 6)	200	7.5 pb^{-1}	57	790 nb^{-1}
2006 (Run 6)	62.4	.08 pb^{-1} **	48	4.2 nb^{-1} **

** initial estimate



(With the rotator on)

No data since Run6….

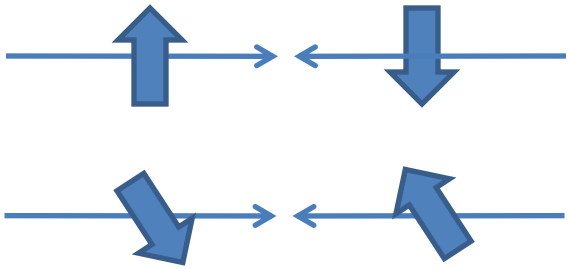
PHENIX datasets

Transversely Polarized Runs

The program for transversity and orbital angular momentum.

Year	√s [GeV]	Recorded L	Pol [%]	FOM (P^2L)
2001 (Run 2)	200	.15 pb^{-1}	15	3.4 nb^{-1}
2005 (Run 5)	200	.16 pb^{-1}	47	38 nb^{-1}
2006 (Run 6)	200	2.7 pb^{-1}	57	880 nb^{-1}
2006 (Run 6)	62.4	.02 pb^{-1} **	48	4.6 nb^{-1} **
2008 (Run8)	200	5.2 pb^{-1} **	45	1100 nb^{-1} **

** initial estimate

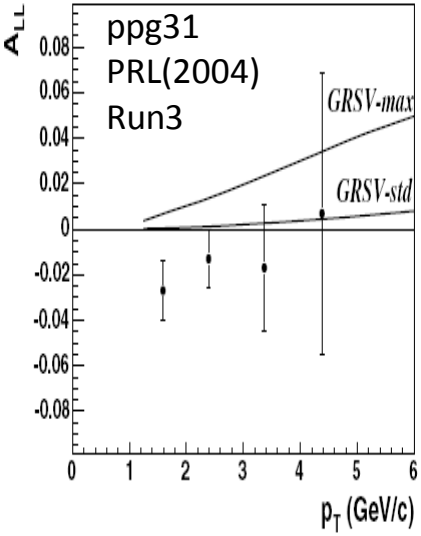


Vertically polarized (the natural direction)

Radially polarized (with the rotator on)

Published results

π^0 A_{LL}



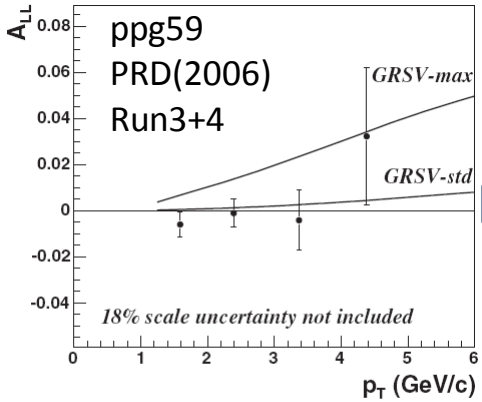


FIG. 2. Run-3+Run-4 combined results on $A_{LL}^{\pi^0}$ versus mean p_T in each bin. Two theoretical calculations based on NLO pQCD are also shown for comparison with the data (see text and [2,8] for details).

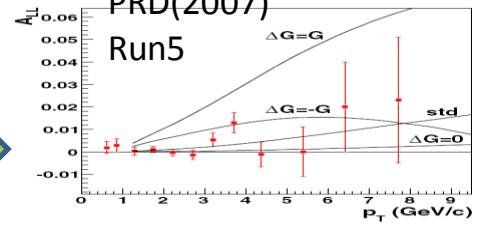
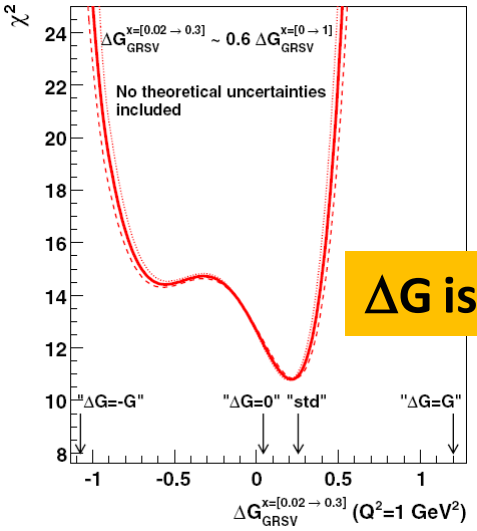


FIG. 2 (color online). The double helicity asymmetry for neutral pion production at $\sqrt{s} = 200$ GeV as a function of p_T (GeV/c). Error bars are statistical uncertainties, with the 9.4% scale uncertainty not shown; other experimental systematic uncertainties are negligible. Four GRSV theoretical calculations based on NLO pQCD are also shown for comparison with the data (see text for details).



ΔG is small!

A_N (central arm)

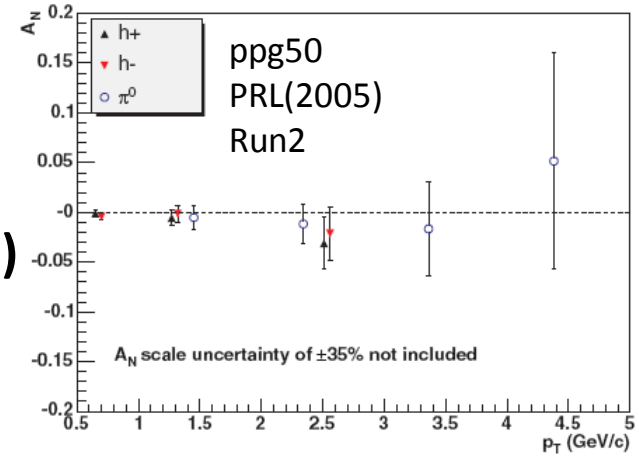


FIG. 2 (color online). Midrapidity neutral pion and hadron transverse single-spin asymmetry A_N vs transverse momentum. Points for positive hadrons have been shifted [illegible] by 50 MeV/c to improve readability. The error bars indicate statistical uncertainties.

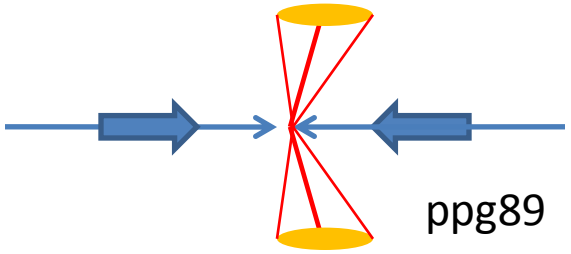
A_N is small!

And
p+p cross section papers, with other PWGs.

(proto) ppgs

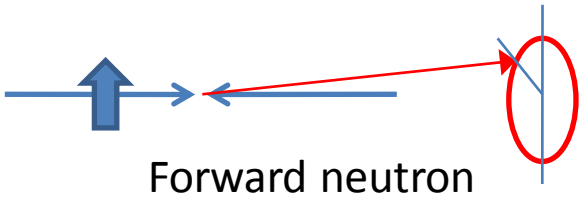
ppg

ppg87 (K. Aoki) π^0 A_{LL} at $\sqrt{s}$=62.4GeV : The x_g range is different.
ppg89 (D. Fields) k_T asymmetry in Double-longitudinally polarized p+p : jet correlation
ppg91 (K. Boyle) π^0 A_{LL} at $\sqrt{s}$=200GeV from Run6



Proto-ppg

Multi-particle A_{LL} (K. Nakano) : "jet" analysis
A_{LL} of eta (F. Ellinghaus) :
Forward neutron cross section and A_N (M. Togawa) : neutrons are tagged by ZDC.

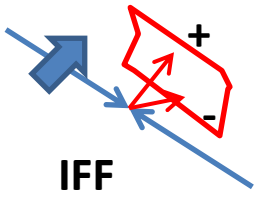


Preliminaries

The list is from the last year.
The current status is

ppg or proto-ppg,
Active,
Not active

2008. 7	**(Run5,6) Prompt mu A_LL, A_L**
	(Run3) Anti-Lambda (D_LL), D_LS, A_LL
2008.6	**(Run6) IFF**
2008.5	**(Run6) Prompt mu A_N**
2008.3	**(Run6) Direct-gamma 62.4GeV (H/P)**
	(Run6) Charged pi A_LL
2007.12	**(Run6) Eta A_LL**
2007.11	**(Run3) anti-Lambda D_LL**
	(Run5) single-e A_LL
2007.10	**(Run5) direct photon A_LL**
2007.7	**(Run5) eta (H/P)**
2007.6	**(Run6) pi0 A_LL**
2007.5	**(Run6) pi0 62.4GeV (H/P)**
	(Run6) MPC pi0 62.4GeV A_N



IFF

Ongoing analysis

From PWG presentations the last year (before preliminary),

Run6 Central arm Sivers (Feng) :
a jet correlation analysis from the transversely polarized data.

Run6 Dimuon A_{TT} (Todd) :
towards the asymmetry of DY process. A direct access to the transversity.

Charged pion cross section study (Astrid):
It supports the A_{LL} result.

Access to low-x region with di-hadron using MPC (John):
A way from inclusive to exclusive probes

Electron (Central arm) and muon (muon arm) correlation study (Mikhail):
An idea to enhance the charm sample.

Anything comes with the spin orientation must be related to the spin structure of the proton.
But what kind of probe is appropriate?

Key points

Basic data for the asymmetry measurement

Polarization of protons : Both absolute value and direction

Relative luminosity : It should be measured by a spin unbiased probe.

For the single azimuthal asymmetry, it can be bypassed.

Statistics and the signal to background ratio

The asymmetry signal is so tiny!

The understanding of spin averaged object

It needs to be collaborated with other PWGs.

Sometimes it is not very clear.

Fight for S/B

$$r \equiv \frac{B}{S+B} \qquad A_S = \frac{A_{S+B} - rA_B}{1-r} \qquad \sigma_S = \frac{\sqrt{\sigma_{S+B}^2 + r^2\sigma_B^2}}{1-r}$$

The ideal case : We know B exactly (σ_B=0)

$$\sigma_S = \frac{1}{\sqrt{N_S} \cdot \sqrt{1-r}}$$

S/B is as important as the integrated luminosity.

π^0

p_T bin (GeV/c)	r background
0.5-0.75	0.814
0.75-1.0	0.577
1.0-1.5	0.373
1.5-2.0	0.261
2.0-2.5	0.175
2.5-3.0	0.127
3.0-3.5	0.102
3.5-4.0	0.089
4.0-5.0	0.084
5.0-6.0	0.081
6.0-7.0	0.081
7.0-9.0	0.079

Table 6: Diphoton yield bund percentage (r in Eq. 4) for Run5 ERT4x4c&&

Prompt photon (with an isolation cut)

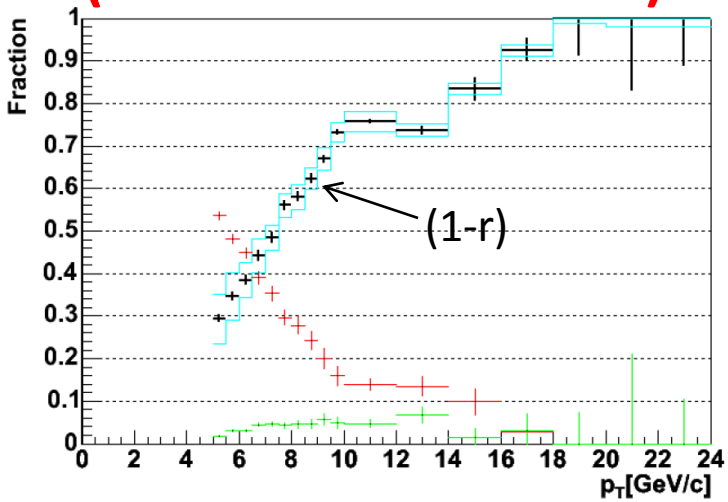


Figure 64: Ratio of each components in Eq. 10 to the total isolated photon. Black: N_s, Red: $N_{\pi^0}R$, Green: n_{π^0}

Table 9: Signal to background ratio and background fraction (r).

Prompt muon

p_T	S/B ratio	r	e_r
1-5	0.408	71.25%	$^{+7.18\%}_{-6.46\%}$
1.75-2.0	0.420	70.45%	$^{+7.60\%}_{-6.32\%}$
2.0-2.5	0.471	67.98%	$^{+6.52\%}_{-5.50\%}$
2.5-3.0	0.492	67.01%	$^{+6.87\%}_{-5.74\%}$
3.0-3.85	0.470	68.05%	$^{+7.75\%}_{-6.53\%}$
3.85-5.0	0.336	75.07%	$^{+7.95\%}_{-7.16\%}$

The understanding of spin averaged object

Multi-particles

- **Partial jet caught in PHENIX**
- **2 (or more) fragmentation function**

Charm, J/psi

- **How to connect the observables to the proton components?**
- **What is the production mechanism?**

kT asymmetry of longitudinally polarized protons (related to ppg89)

- **Is there centrality class in proton-proton collisions?**

Hard/soft separation

- **The factorization scheme doesn't work in the soft process.**

(It's an issue, especially when we see no asymmetry.)

Be as simple as possible!

The future

Integrated L goals:

From RHIC Spin Plan Report (June 9,2008)

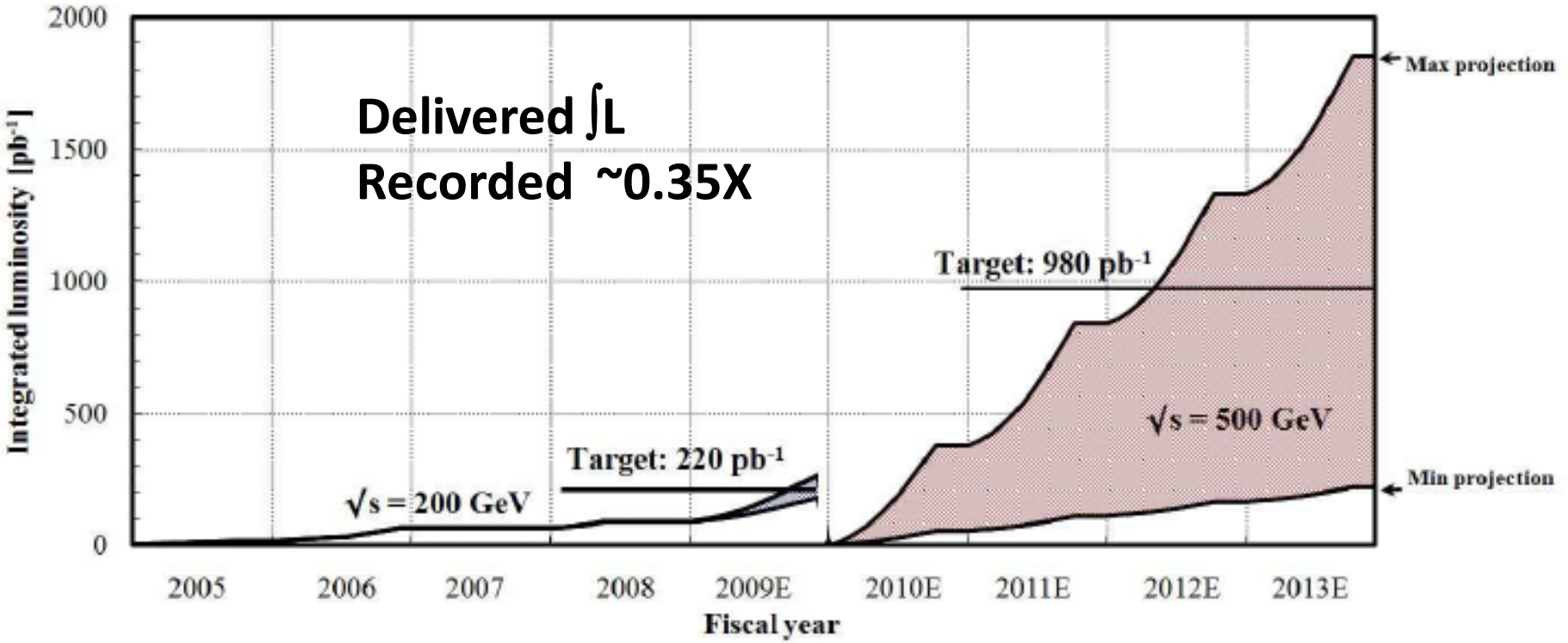
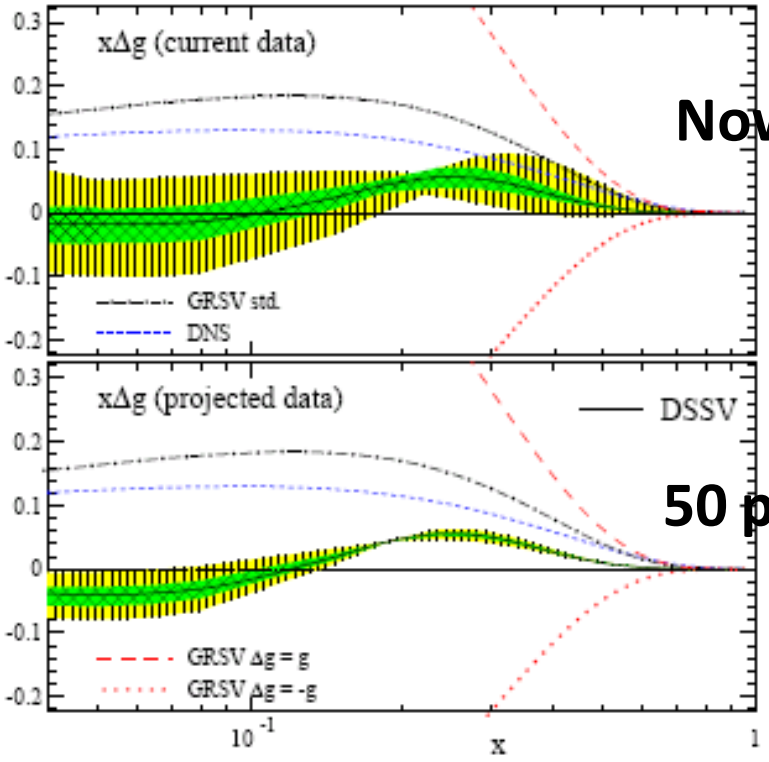


Figure 1: *Minimum and maximum projected integrated luminosity through FY2013. Delivered luminosity numbers are given for one of two interaction points, and a physics running time of 15 weeks in FY2009, and 10 weeks of physics operation per year thereafter. The assumed center of mass energy is 200 GeV until the end of FY2009, and 500 GeV thereafter.*

Global fit with RHIC + DIS

de Florian, Sassot, Stratmann, Vogelsang, arXiv:0804.0422



Now

50 pb^{-1}

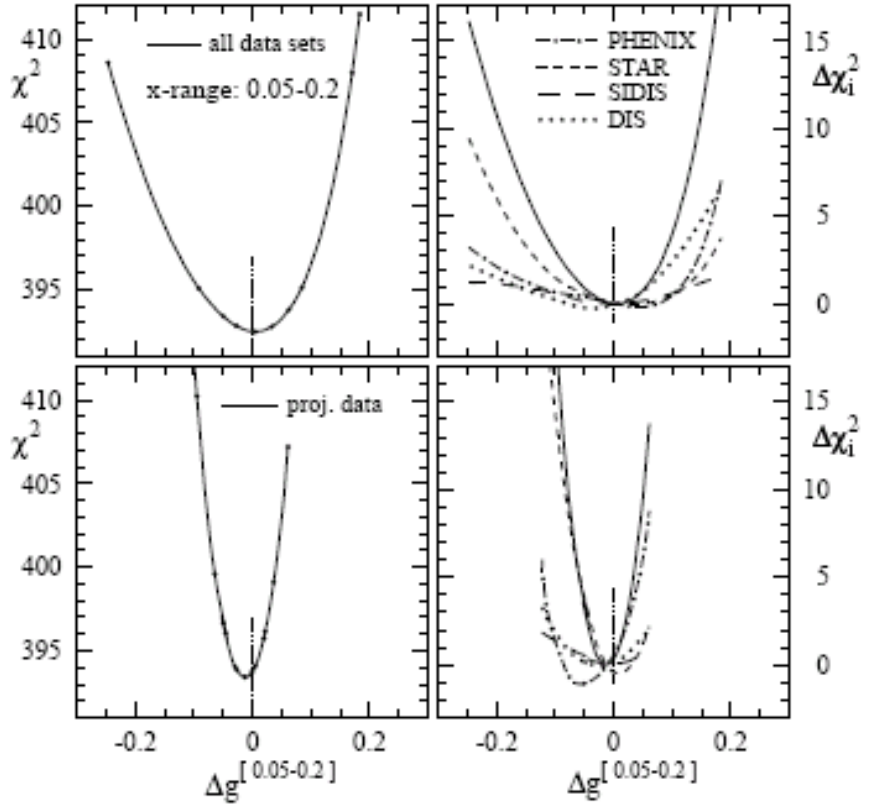


Figure 5: *Upper row: $x\Delta g$ ($Q^2 = 10$ GeV^2) from the global NLO QCD analysis by DSSV [14] (left) and partial contributions $\Delta\chi_i^2$ of the fitted data sets to the total χ^2 for variation of $\int_{0.05}^{0.2} \Delta g(x)dx$ (right). The uncertainty bands correspond to $\Delta\chi^2 = 1$ (green/cross-hatched) and $\Delta\chi^2/\chi^2 = 2\%$ (yellow/vertically hatched). Also shown are results for $\Delta g(x)$ from previous GRSV [45] and DNS [47] analyses. Lower panels: same as above when the RHIC data errors are scaled down by a factor of 4 as expected from the next long RHIC pp run at 200 GeV (50 pb^{-1} with a polarization of 60%).*

W physics in $\sqrt{s}$=500 GeV

The parity violating process is to decompose the anti-quark flavor.
Observables : A_L of electrons and muons from the W decay.

W -> e (central arm)
W -> mu (muon arm)

How much is the QCD backgrounds?
Is the momentum resolution enough?

The MC estimations need to be confirmed by the real data.

Beyond Run9

The detector upgrades

VTX, FVTX, NCC, W-trigger

Heavy flavor tagging

Increase the acceptance → It helps determination of the kinematics

Drell-Yan transverse single spin asymmetry

Check fundamental QCD prediction of sign change in Sivers asymmetry between Drell-Yan and semi-inclusive DIS

Outlook

Recorded Luminosity	Main physics Objective	Remarks
~50pb^{-1}	Gluon polarization using di-jets and precision inclusive measurements	200 GeV
~100pb^{-1}	W production (Important consistency check to DIS results - Phase I) Gluon polarization (Di-Jets / Photon-Jets)	500 GeV
~300pb^{-1}	W production (Constrain antiquark polarization - Phase II) Gluon polarization (Di-Jets / Photon-Jets)	500 GeV
~30pb^{-1}	Transverse spin gamma-jet	200 GeV
~250pb^{-1}	Transverse spin Drell-Yan (Long term)	200 GeV

(BNL PAC talk May 2008)

P=.7; running time is critical.

Spinfests

2005 at RIKEN (July 11- September 2)
2006 at BNL (July 24 – September 1)
2007 at BNL (March 19 – April 6) (analysis only)
2007 at RIKEN (June 11 – July 27)
2008 at BNL (July 21 – August 8)
2009 in Hawaii?

Goals

To integrate new people and get to know each other
Discussion (deeper than regular PWG meetings)
Theory lectures
~~**Complete one's analysis**~~

Sponsored by RIKEN, LANL

Summary

- Inclusive π^0 has been the only probe of the gluon polarization published for now. As the integrated luminosity is increased, other inclusive probes ($\pi^{\pm}$, direct photon, heavy quarks) get to be in the scope. In addition, di-jet (di-hadron) analysis determines the kinematics. And the jet correlation itself can be a spin probe.

- The field of transverse spin physics is still developing rapidly. A number of inclusive A_N analyses from Runs 6 and 8 still need people to work on them!

- We need 30 times more integrated luminosity in $\sqrt{s}$=200GeV to meet the original plan. (The A_{LL} of direct photon) Another program with $\sqrt{s}$=500GeV is also exciting.

- The spinPWG is actively working on Run5,6,8 data.

BACKUP SLIDES

Published results

ppg31

Double Helicity Asymmetry in Inclusive Mid-Rapidity neutral pion Production for Polarized p+p Collisions at sqrt(s)=200 GeV

Phys. Rev. Lett. 93, 202002 (2004)

Run3 pi0 A_LL

ppg50

Measurement of Transverse Single-Spin Asymmetries for Mid-rapidity Production of Neutral Pions and Charged Hadrons in Polarized p+p Collisions at sqrt(s) = 200 GeV

Phys. Rev. Lett. 95, 202001 (2005)

Run3 pi0, h A_N

ppg59

An Update on the Double Helicity Asymmetry in Inclusive Midrapidity π^{0} Production for Polarized $p+p$ Collisions at $\sqrt{s}=200$ GeV

Phys. Rev. D 73, 091102(R) (2006)

pi0 A_LL, update (Run3+Run4)

ppg63

Inclusive cross section and double helicity asymmetry for pi^0 production in p+p collisions at sqrt(s)=200 GeV:
Implications for the polarized gluon distribution in the proton

Phys. Rev. D 76, 051106 (2007)

pi0 A_LL, update chi2 (Run5)

(proto) ppgs

2008b	Spin	M.Togawa;G. Bunce, S.White,Y.Goto,K.Tanida						84	18-Apr-08	2008b	5	p+p	200 GeV	A_N	forward neutron x-sect and A_N; M.Togawa
2007l	Spin	F. Ellinghaus; J.Seele,E.Kinney,C. Aidala						210	14-Dec-07	2007l	5,6	p+p	200 GeV	A_LL,eta	x-sect, A_LL eta, comp.to pi^0; F. Ellinghaus
2007k	Spin	K.Nakano;Y.Akiba,Y.Goto,J.Lajoie,T.-A.Shibata						302	13-Sep-07	2007k	6	p+p	200 GeV	A_LL	Event structure&A_LI in part. cluster; K.Nakano
2007i	Spin	K.Boyle; A. Bazilevsky, G. Bunce, A. Deshpande						332	14-Aug-07	2007i	6	p+p	200 GeV	A_LL,pi^0	delta G from pi^0 A_LL; K. Boyle
089	Spin	hep-ex		wrk		PRL	PPG formed	4	7-Jul-08	2007g	5	p+p	200 GeV	di_h,crl	k_T asymmetry di-h correl.long.pol.;Doug Fields
PPG #	PWG	arXiv	IRC for med	w/us	w/jrn	jrn.	last action	days	last act'n	PPG #	Run(s)	CollSys	sqrt(sNN)		Description and PPG Head Name
087prd	Spin	hep-ex	*2-Jun-08*	int1		prd R	first int. revue	56	16-May-08	087prd	6	p+p	62.4 GeV	A_LL,pi^0	pi^0 incl. X-sect & A_LL; K. Aoki

Preliminaries

2008. 7 (Run5,6) Prompt mu A_LL, A_L
(Run3) Anti-Lambda (D_LL), D_LS, A_LL

2008.6 (Run6) IFF

2008.5 (Run6) Prompt mu A_N

2008.3 (Run6) Direct-gamma 62.4GeV (H/P)
(Run6) Charged pi A_LL

2007.12 (Run6) Eta A_LL

2007.11 (Run3) anti-Lambda D_LL
(Run5) single-e A_LL

2007.10 (Run5) direct photon A_LL

2007.7 (Run5) eta (H/P)

2007.6 (Run6) pi0 A_LL

2007.5 (Run6) pi0 62.4GeV (H/P)
(Run6) MPC pi0 62.4GeV A_N

Recent activities

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```
2008.7  9  Run6 pi0 A_LL (Kieran)
2008.6 25 Run5/6 prompt-mu A_LL (Xiaoron)
       18 Run6 eta (Frank)
          Run8 vernier scan (Amaresh)
       11  Run5/6 prompt-mu A_LL (Xiaoron)
          Run3 Anti-Lambda asymmetry (Gerry)
       04 kT asymmetry (Imran)
          Run6 Central arm Sivers (Feng)
2008.5 21 Run5/6 prompt-mu A_LL (Xiaoron)
          IFF analysis (Ruizhe)
       14 IFF analysis (Ruizhe)
       07 prompt-mu A_N (Han)
          Multiparticle A_LL proto-ppg (everybody)
2008.4 30 prompt-mu A_N (Han)
          Multiparticle A_LL proto-ppg (Kenichi)
       23 prompt-mu A_N (Han)
          Physics possibilities with a retracted HBD (Dave)
       16 Run5/6 prompt-mu A_LL (Xiaoron)
          Forward neutron analysis (Manabu)
          Final Run6 pi0 A_LL (Kieran)
          IFF analysis (Ruizhe)
       07 --Special meeting for BUP---
          Run-09 MPC pi0 A_LL projections (John)
          Collection of plots for BUP (Sasha)
          pi0 expectations (Kieran)
          charged pion A_LL curves (Swadhin)
       02 Run-09 MPC pi0 A_LL projections (John)
          theory curves, diff rapidity (Swadhin)

2008.3 26 Run6 200GeV Transverse relative luminosity status (Nathan) << where it
 goes?
          BUP discussion (Sasha,Kieran)
       12 Dihadron mesurements (Ming,Astrid,Han)     << a new direction?
          Run6 charged pion A_LL (Astrid)
          prompt photon at 62.4GeV (Kohichi)
          spinDB (Todd)
          delta-g from pi0 A_LL and prospects for Run9 (Kieran)
       05 prompt photon at 62.4GeV (Kohichi)
          Run6 charged pion A_LL (Astrid)
          Run6 dimuon transverse asymmetries (Todd)  << follow up?
          Study of optimal energy for delta-g (Sasha)
2008.2 27 spinDB (Ruizhe)
          Run6 Central arm Sivers (Feng)
       20 Run6 200GeV Transverse relative luminosity status (Nathan)
       13 prompt photon at 62.4GeV (Kohichi)
          Run8 local pol status (Seishi)
       06 Run8 local pol status (John,Seishi)
          STAR scaler boards (Robert)
          Run8 EMCal online calibration (Kensuke)
2008.1 23 IFF analysis (Ruizhe)
          kT asymmetry (Imran)
          Run6 charged pion A_LL (Astrid)
       16 pi0 A_LL at 62.4GeV ppg request (Kazuya)
          Discussion of Run8 goals
       09 Ru8 planning (Kensuke)
2007.12 19 IFF analysis (Ruizhe)
       11 Run6 eta A_LL (Joe)
          Run6 charged pion A_LL (Astrid)
          kT asymmetry (Imran)
          Summary of Run8 discussion at RSC meeting (Sasha)
          Run6 eta & pppg formation(Frank)
       05 prompt photon at 62.4GeV (Kohichi)
          anti-Lambda spin transfer (Ran)
          Run6 200GeV Transverse relative luminosity status (Nathan)
2007.11 28 Run6 eta A_LL (Joe)
          IFF analysis (Ruizhe)
          Run8 planning discussion
       14 Run5 full jet reconstructin (Yue Shi) << H/P
       01 anti-Lambda spin transfer (Ran)
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```
          Run5 single electron A_LL (Patty)     <<  Seishi?
          Run5 rel.lumi Run5 (Patty)
2007.10 24 pi0 A_LL at 62.4GeV pPPG status(Kazuya)
          low x (PYTHIA) (John)                 << Where it goes?
       17 Run6 charged pion A_LL (Astrid)
2007.9  26 anti-Lambda spin transfer (Ran)
          MPC DNP talks (Aron,Veicht,John)
          IFF analysis (Ruizhe)
          Run5 direct photon A_LL (Robert)
       19 Run6 charged pion A_LL update (Christine)
          IFF analysis (Ruizhe)
       05 Run5 Multiparticle A_LL (Kenichi)
          Effect of Multiple collisions on Rel. Lum (Amaresh) << Run9?
          Run5 direct photon A_LL (Robert)
2007.8  22 Run5 direct photon cross section to the final (Kensuke)
          Run5 Multiparticle A_LL (Kenichi)
          Update on Rel.Lum. in Run6 62.4GeV (Kazuya)
2007.7  25 Parity violation in Au+Au collisions (IhnJea) << where it goes?
          Spinfest summary (Kensuke)
       18 Run6 long production (Joe)
          prompt photon at 62.4GeV (Kohichi)
          Run6 Central arm Sivers (Feng)
2007.6  27 anti-Lambda spin transfer (Ran)
       13 Run6 Local pol for pi0 A_LL (Seishi)
          Run6 pi0 A_LL lower-pT preliminary request (Kieran)
          Discussion on spinfest plans and goals
       08 Run6 pi0 A_LL lower-pT preliminary request (Kieran)
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June 2007 ~ July 2008
Presentations at SpinPWG